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Using Response Surface Methodology As an Approach to Understand and Optimize Operational Air Power

Marvin L. Simpson, Jr.

Resit Unal

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14. ABSTRACT
The Air and Space Operations Center (AOC)1 Command and Control data center node is the senior air power element on any battlefield. The AOC provides the Commander the capability to plan and execute theaterwide air and space operations. Two primary documents are created daily the Air Tasking Order (ATO) and the Airspace Control Order (ACO). In any operation involving air power, usually a single commander is responsible for the air power force. In a theater-size military campaign as many as 2500 people inside a Combined Air Operations Center (CAOC) move massive amounts of information across multiple networks. The CAOC provides the Commander the capability to direct and supervise activities of assigned or attached forces and monitor the actions of both enemy and friendly forces. The ATO and ACO promulgate his will throughout his command. Advanced optimization methods and statistical sampling techniques may significantly help quantitatively model and understand the interaction of combatants. This article explores the use of Response Surface Methodology (RSM) as an approach to understand and optimize operational air power and illustrates its application using an operational training system in conjunction with a fictitious force-on-force scenario.

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Using Response Surface Methodology As an Approach to Understand and Optimize Operational Air Power

Marvin L. Simpson, Jr. (OPTECH Inc., USA)

Resit Unal (Old Dominion University, USA)

Abstract

The Air and Space Operations Center (AOC)[1] Command and Control data center node is the senior air power element on any battlefield. The AOC provides the Commander the capability to plan and execute theater-wide air and space operations. Two primary documents are created daily: the Air Tasking Order (ATO) and the Airspace Control Order (ACO).

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Advanced optimization methods and statistical sampling techniques may significantly help quantitatively model and understand the interaction of combatants. This article explores the use of Response Surface Methodology (RSM) as an approach to understand and optimize operational air power and illustrates its application using an operational training system in conjunction with a fictitious force-on-force scenario.

1. For the purpose of this article, the terms CAOC and AOC are synonymous. The Joint Force Air Component Commander (JFACC) is the senior airpower leader; the CAOC/AOC is his supporting staff and/or their physical location.

Introduction

Humans are notoriously bad at visualizing any mathematical relationship beyond a direct or proportional linkage. Modern techniques help eliminate this condition. A *plumb bob* is an ancient tool used to create the Egyptian pyramids and, if one digs deep into most plumbers or carpenters' toolboxes, one can find that tool today, modified, but recognizable to any ancient Egyptian construction foreman. Command and Control (C2) has been around at least as long as plumb bobs, but using the same tools the ancients used does not guarantee success. When one thinks of the best "ancient" air power commanders it is easy to envision the "old-fashioned" fighter pilot: a natural leader and an intuitive tactician leading his command to victory.

The Wright brothers advanced aviation not by improving the understanding of lift, but by mastering the interactions of control. During the Vietnam War, flying F-4 Phantoms or F-105 Thunderchiefs was dangerous work. Col. Robin Olds, the commander of the 8th Tactical Fighter Wing, came up with the qualitative strategy of luring North Vietnam's MiG-21s into battle with F-4s masquerading as the more vulnerable F-105s (Scutts 1988). The operation was named *Bolo*. It required a massive Air Force-wide effort to bring it to fruition. The battle was a total success. Thirty-plus years later, we still qualitatively create air battle plans. The question explored is "Can the science of control be used to help quantitatively understand and optimize the interaction of air combatants?" Sun Tzu said: "If you know the enemy and know yourself you need not fear the results of a hundred battles" (Giles 1910). Therefore, the goal of this article is to explore whether the use of a strict quantitative technique has viability when used on a problem set as complex as combat air power.

What is an AOC?

Today, the Air and Space Operations Center (AOC)[2] Weapon System, AN/USQ-163 Falconer, military C2 data center node is the senior element of the Theater Air Control System on the battlefield (Kometer 2005). The primary function of the divisions of the AOC is to produce and execute an Air Tasking Order (ATO) and associated documents like the Airspace Control Order (ACO). The Air Force fielded five permanent Falconers worldwide to meet continuing air power challenges. In any operation involving air power, a single commander is designated the responsible member for all air power forces assigned and attached. In a theater-size military campaign, as many as 2500 people inside the Combined AOC (CAOC) move massive amounts of information across multiple communication networks of various security levels. The Falconer is the core production hub of the much larger CAOC facility/compound. The entire CAOC provides the Commander the capability to direct the activities of assigned, supporting, or attached forces and monitor the actions of both enemy and friendly forces. Walking into any of the five worldwide CAOCs for the first time is an extraordinary experience. It is just what you expect of the nerve center of the most powerful Air Force on earth. Huge projection screens show the exact location of every military aircraft flying over the theater of operations; CNN, Fox, and other news organizations; and other situation displays. Rows of professional warriors operate computer screens and banks of telephones communicating worldwide while absorbing vast amounts of information from organizations across the planet. The Combined Force Air Component Commander (CFACC) sits in a room with his key staff. Video and data screens show live feeds from various sensors over the battlefield. Chat rooms on computer screens exchange information across all security levels. An interest-

2. For the purpose of this article, Joint Force Air Component Commander (JFACC) and Combined Force Air Component Commander (CFACC) are synonymous.

ing question to be asked is whether these modern warriors' efforts can be changed from their qualitative approach and augmented with quantitative tools?

What is an ATO?

With all this command and control technology, an assertion is that the most critical weapon of war is the human mind; the rest can be viewed as just tools. To understand complex processes such as air war, it may sometimes be best to combine all the variables into simplified models that can represent their interactions. The ATO and ACO are the documents used to disseminate the commander's plan for all combat air power forces. For an aviator, these are the only two documents provided by higher headquarters to answer the question, *what am I doing tomorrow?* The ATO and ACO are United States Message Text Format (USMTF) military messages that provide a written description of the next day's air battle plan. Based on experience, the goal of building the ATO/ACO is to provide a single source document for everything that flies and provide awareness to other combatants in the Area of Responsibility (AOR), and anything that uses airspace within the AOR, in the next 24-hour period. These documents may be hundreds of pages of computer printout traditionally approved and transmitted 12 hours before execution. "In the AOC, two separate networks exist and there are limited touch points. One is a technical network that conveys data and the other is a human command network that analyzes or synthesizes that data transforms it to information, and produces decisions that result in output. These independent networks converge at the individual personal computer (PC). In a combat AOC, there are generally three to ten computers at each person's workspace" (Simpson 2008). As the technical infrastructure moves to service oriented architecture (SOA), there will be little change to human driven constraints dictated in building an ATO.

There is a 12-hour period between publication of the ATO and the start of the battle plan. As soon as the tactical units receive the ATO/ACO, they begin detailed planning to create mission-planning folders for the aircrews. At the same time, maintenance receives the ATO, builds the ordnance required, and starts loading the aircraft. The time between D-12 and D+0 is critical for these functions to accrue. At D+0 hours, execution of the ATO and implementation of the ACO occurs. The CAOC makes adjustments as the battle unfolds. These adjustments can be minor, such as approving a Time on Target (ToT) change by 15 minutes due to a wing maintenance delay, or so major that every line of the ATO is rendered invalid and the order must be recreated. It is very hard for any Commander to visualize and optimize the interactions of all these moving parts.

Understanding Interactions: An Approach

The AOC is an organization that, on its best days, is qualitatively efficient and accurate in its planning and execution. A qualitative approach augmented with quantitative techniques may have the potential to improve the efficiency, accuracy, and specificity required in the operational planning and tactical delivery of air power. If one considers an Air Battle Plan as a large-scale black box of interactions, it is easier to comprehend than all the individual moving actions. Tanker and other support aircraft become binding agents and weapons and enemy actions become catalysts of change. From this perspective, system parameter design techniques using RSM can be applied to quantitatively model and study operations. System design is the process of applying knowledge to produce a basic functional design and, in this case, it would produce a qualitatively created ATO. The original ATO created by the AOC would define the attributes of the Air Battle Plan undergoing analysis. Assuming zero transportation time, the maximum analysis time would only be 12 hours. The qualitative initial design may be functional, but it may be far from optimal, in terms not easily visualized by experts creating it. The objective in parameter design is to identify the settings

that optimize the desired performance characteristic (Phadke 1989; Kackar 1985). We often see Subject Matter Experts (SMEs) in the AOC working qualitatively until the plan "looks good" or they run out of time to do anything different. Experimenting with the design variables either one at a time or by trial and error is a common approach to optimization (Phadke 1989; Bendel 1988). However, this approach can lead to a very long and expensive time span for completing the design. Furthermore, when using a *one variable at a time* approach, parameter interactions that may affect the optimum results may not be identified (Gunter 1990). The result in most cases is a product design (ATO) that may be far from the most advantageous. To determine the optimum conditions, a *full factorial* approach in which all possible combinations of parameter values are tried may be necessary. However, it must be noted that as the number of parameters studied increased, a full factorial approach quickly grows exponentially large, e.g., 13 factors at three levels would require studying 1,594,323 (3^{13}) experiments.

Understanding Interactions: Assumptions

To validate that a quantitative approach is possible to study improving an ATO, the factors are limited to four different types of aircraft assigned to various units at two different levels (full up and 30% reduced). It is assumed the aircraft would have forward-firing missile ordnance, require air refueling, and go well beyond the forward edge of the battle area or be purely defensive air-to-air aircraft. The model used to simulate combat was an operational training tool named Command and Control Weapon System Part Task Trainer (C2WSPTT) (pronounced chew-spit) used to fly out ATOs and simulate combat to an AOC training audience. C2WSPTT was the only model readily available to accomplish the necessary data runs. The scenario selected was an unclassified training scenario previously created to provide AOC operators basic training. To make the unclassified scenario robust, we used a training scenario that had 631 pieces of airspace, 550 blue (friendly) missions, and 197 red (enemy)

missions. Consequently, if the ATO were run, it would complete 24 hours of missions in approximately 25 minutes. Sixteen experimental test runs would require a little more than half of the 12 hours traditionally available. The reported speed is 65 times normal. When a real ATO is flown with all the factors associated with combat, the maximum speed of C2WSPTT is about 2.5 times normal operating on commercially available computer platforms. To ensure no aircraft was shot down from ground by Surface to Air Missiles (SAMs), we turned them all (both red and blue) off, as the SAM factor would have overwhelmed the number of red aircraft destroyed. Normally, Intelligence will brief two scenarios for enemy actions, *most likely* and *worst case*. We were only able to create one red ATO; therefore, it was flown against the *most likely* scenario only. Without knowing the conceptual foundation or algorithms of C2WSPTT, potential stochastic variation in ATO fly out was minimized by elimination of the same mission numbers in the ATO whenever the 30% reduction was required.

With the parameters of the simulation in place, we were ready to explore if an engineering quantitative method may be used to optimize an ATO. RSM is a set of mathematical and statistical techniques for analysis designed to create a mathematical model to efficiently explore the effects of a set of parameters. Using RSM in a military setting is a valid experiment as defined by the *Code of Best Practice for Experimentation* (Alberts et al. 2002). In the case of combat air power, the variables were number of blue aircraft lost (minimized) and number of red aircraft destroyed (maximized). Using experimental design methods, RSM seeks to relate a *response* or *output* characterized to the values of a number of *predictors* or *input* variables that affect it (Box and Draper 1987). Response can be defined as the performance or quality characteristic of interest (e.g., yield, weight, number of aircraft). These techniques, introduced by Box and Wilson (Myers 1971) and later expanded by others, consist of designing the experiment and the subsequent analysis of experimental data (Cornell 1990). RSM may lead to a rapid and efficient exploration of the ATO and to estimated optimum conditions within limited time and experimental data.

Steps Involved in Parameter Design

There are six steps in a typical parameter design (Phadke 1989):

a. Identify the characteristic to be observed,

b. Identify the factors and levels,

c. Define the most likely interactions between parameters (factors),

d. Design the matrix experiment required and define the data analysis plan,

e. Conduct the experiments,

f. Analyze the data to determine optimum levels of factors.

The first four steps are required for planning the experiment. In the fifth step, the experiments are conducted. In this case, the operational training system is run. In step six, experimental results are analyzed, optimum levels are determined, and a confirmation experiment is conducted to verify results (i.e., if an experiential run does not contain the optimization of the expected factors).

The details of these six steps are described below.

Identify the characteristic to be observed and the functions to be optimized

Traditionally, friendly military forces are defined as "blue force" and enemy forces are defined as "red force." Primary functions for optimization experimented within this initial trial will be the number of blue aircraft lost and number of red aircraft destroyed. The characteristic to be observed in this case is the number of aircraft

(Y function). The objective is to determine the optimum combinations of design parameter values to minimize the number of blue aircraft lost and, at the same time, maximize the number of red aircraft destroyed. We will be emulating, as best we can quantitatively, *Operation Bolo*.

Identify the factors and levels

In this study, two levels of each parameter were studied: a high (level-1) and a low (level-2) value (Unal, Stanley, and Joyner 1993). Factors and values of the four variables selected for study are in Table 1. Level-1 factor represents units that are fully manned, trained, equipped, and totally capable of engaging the enemy. Seventy percent was selected as level-2 to demonstrate units that were less competent but still an effective fighting force.

Table 1. Factors and levels

Factors		**Level-1 (Yates -1)**	**Level -2 (Yates +1)**
A	F18 Units	100%	70%
B	F16 Units	100%	70%
C	F15C Units	100%	70%
D	F15E Units	100%	70%

The levels represent an outcome that a commander would require to be studied such that, for various combinations of parameters, it would remain reasonable.

Define the most likely interactions between these parameters (factors)

Varying several factors simultaneously may have interactive effects on our *black box* that affects the optimum solution. When the effect of one parameter depends on the level of another, an interaction is said to exist (Kackar 1985). It is important to understand the interactions to find optimum minimal and maximal relations. For this operational air power problem, it was difficult to estimate which pairs of parameters will have the strongest interactions. Therefore, we investigate all interactions that may be significant.

Design the matrix experiment required and define the data analysis plan

Using Yates's algorithm (Myers 1971) to code the experiments, one would expect the main functions to react as depicted in Table 2 and the interaction functions as in Table 3. Instead of writing each number in detail, Yates's algorithm allows a *-1* to indicate high level and a *+1* to indicate a low level. The algorithm requires starting with *-1* and then alternating to a *+1*. Each additional column of factors requires alternating signs in pairs.

Table 2. Main Effects

	Main Factors			
Experiment Number	**A**	**B**	**C**	**D**
1	-1	-1	-1	-1
2	+1	-1	-1	-1
3	-1	+1	-1	-1
4	+1	+1	-1	-1
5	-1	-1	+1	-1
6	+1	-1	+1	-1
7	-1	+1	+1	-1
8	+1	+1	+1	-1
9	-1	-1	-1	+1
10	+1	-1	-1	+1
11	-1	+1	-1	+1
12	+1	+1	-1	+1
13	-1	-1	+1	+1
14	+1	-1	+1	+1
15	-1	+1	+1	+1
16	+1	+1	+1	+1

Table 3. Interaction Effects

	Interactive Factors					
Experiment Number	**AB**	**AC**	**AD**	**BC**	**BD**	**CD**
1	+1	+1	+1	+1	+1	+1
2	-1	-1	-1	+1	+1	+1
3	-1	+1	+1	-1	-1	+1
4	+1	-1	-1	-1	-1	+1
5	+1	-1	+1	-1	+1	-1
6	-1	+1	-1	-1	+1	-1
7	-1	-1	+1	+1	-1	-1
8	+1	+1	-1	+1	-1	-1
9	+1	+1	-1	+1	-1	-1
10	-1	-1	+1	+1	-1	-1
11	-1	+1	-1	-1	+1	-1
12	+1	-1	+1	-1	+1	-1
13	+1	-1	-1	-1	-1	+1
14	-1	+1	+1	-1	-1	+1
15	-1	-1	-1	+1	+1	+1
16	+1	+1	+1	+1	+1	+1

The data analysis approach will use a combination of response tables and regression analysis to determine the interactions of the combatants. Interactive factors are assumed to be bidirectional and result from the interaction of factors.

Conduct the experiments

The results of the 16 experiments are presented in Table 4. Complete records of the experiments are available in Appendix A.

Table 4. Blue/Red Aircraft Lost

	Main Factors					
Experiment Number	A	B	C	D	Blue Lost Y	Red Lost Y
1	-1	-1	-1	-1	36	56
2	1	-1	-1	-1	39	56
3	-1	1	-1	-1	35	54
4	1	1	-1	-1	35	54
5	-1	-1	1	-1	39	56
6	1	-1	1	-1	34	56
7	-1	1	1	-1	34	53
8	1	1	1	-1	33	52
9	-1	-1	-1	1	34	56
10	1	-1	-1	1	35	57
11	-1	1	-1	1	37	53
12	1	1	-1	1	33	55
13	-1	-1	1	1	33	55
14	1	-1	1	1	33	55
15	-1	1	1	1	35	53
16	1	1	1	1	39	55

Analyze the data to determine optimum levels of factors

Since the experimental design is orthogonal, it is possible to separate the effect of each parameter (Bryne and Taguchi 1986). The average weights for each factor (as explained below) were calculated and presented in the following response tables.

Table 5. Blue Aircraft Lost Sensitivity (R^2 very low)

	Factors			
	A (F18)	B (F16)	C(F15C)	D(F15E)
Level-1	35.125	35.125	35	34.875
Level-2	35.375	35.375	35.5	35.625
Sensitivity	-0.25	-0.25	-0.5	-0.75

Table 6. Red Aircraft Destroyed Sensitivity (R^2 High)

	Factors			
	A (F18)	B (F16)	C(F15C)	D(F15E)
Level-1	55	53.625	54.375	54.875
Level-2	54.5	55.875	55.125	54.625
Sensitivity	0.5	-2.25	-0.75	0.25

The response tables show the loss of aircraft effects of the factors at each level. These are separate effects of each factor commonly called main effects (Phadke 1989). The average aircraft lost/destroyed in the response table are calculated by taking the average from Table 4 for a factor at a given level, every time it was used. As an example, the factor *A* (F18s) was at level-2 (annotation in table 4 being [-1]) in experiments 1, 3, 5, 7, 9, 11, 13, and 15. The average of blue aircraft lost is shown in the response in Table 5 under *A* at level-2 (annotation being [+1]). This procedure is repeated and the response table is completed for all factors at each level.

The number of aircraft lost/destroyed effect sensitivity is computed by taking the difference between the largest and smallest number for a given factor. The response table for blue aircraft lost reveals that the number of F15E shows the greatest sensitivity, meaning that the

largest effect on blue aircraft lost is realized by varying this factor. The response table for our maximization problem of red aircraft destroyed reveals that number of F16, factor *B*, shows the greatest sensitivity (absolute value of factor *B* level-1 minus factor *B* level-2, in Table 6), meaning that the largest effect on red aircraft destroyed is realized by varying this factor. Similarly, blue aircraft lost factor *A* (F18s) and factor *B*, F16, shows the least sensitivity (Table 5 factor *A* and *B*). Additionally, factor *D* (F15Es) shows the least sensitivity to red aircraft destroyed (Table 6). The average aircraft lost/destroyed for blue aircraft lost factor *A* (Table 5) and red aircraft destroyed factor *B* (Table 6) are also graphed. Blue effects were "weak" when compared to the much smaller numbers in Table 5 as compared to the -2.25 number generated in Table 6.

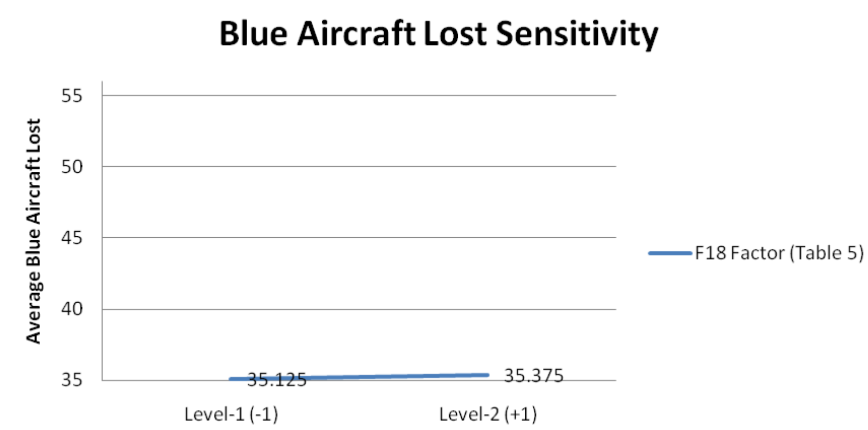

Figure 1. F18 Sensitivity

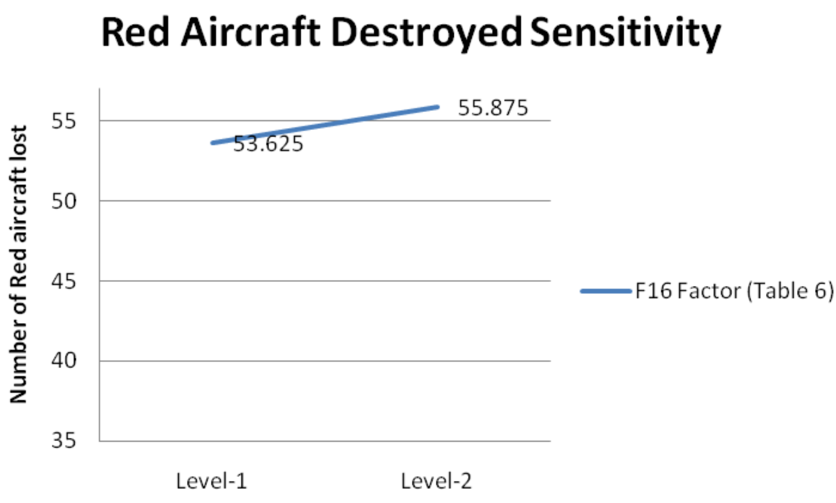

Figure 2. F16 Sensitivity

To estimate factor interaction effects, a two-way interaction response table is prepared from the observed data. The analysis of interactions show that factor *B* (F16) X *D* (F15E) interaction for blue aircraft and factor *A* (F18) X *D* (F15E) interactions for red aircraft exists. However, these interaction effects are much less relative to the strong *B* (F16) main effect. Using the same procedure, interaction response tables and plots can be used to analyze all other factor interactions to be studied. Overall, for this one ATO, interactive effects turned out to be weak.

The optimum levels for the four factors can now be selected by choosing the level to minimize or maximize to reach a desired outcome. In the two cases investigated, the minimum blue aircraft losses are under the following conditions:

Table 7. Minimum Blue Loses

A	1	F18 70%
B	1	F16 70%
C	1	F15C 70%
D	-1	F15E 100%

With a Y (min) of Blue aircraft lost:

Y (min) = 33.75

Table 8. Maximum Red Loses

The maximum Red aircraft destroyed under the following conditions:

A	-1	F18 - 100%
B	1	F16 -70%
C	1	F15C -70 %
D	-1	F15E -100%

With a Y (max) Red aircraft destroyed:

Y(max) = 56.75

The blue losses minimize math model 33.75, which is within the low range (33-34), implying we can minimize F18, F16, and F15C and keep F15E at full strength. The red losses maximize math model 56.75, which is within the high range (56-57), implying we can

minimize F16 and F15C and keep F15E and F18 at full strength. The operational analysis is that one can assign F15C and F16 units some slack (i.e., a 30% reduction in sorties) in flying one day without major impact to one day of the war effort (blend Experiment 10 and 11). Those results are based on the linear math model obtained using RSM design. Linear regression provides a R^2 value allowing the determination of how good one term is as a predictor of another. The higher value of R^2 is the better predictor. The model for blue lost was weak as it had a low R^2 value. This result indicated the need for a more complex math model and/or other factors not included in the study were in play. The math model for red aircraft lost was much stronger with a higher R^2 value indicating a higher confidence in the results.

Conclusions

One of the goals of systems engineering is optimization beyond a single node. This article explored a quantitative approach (RSM) in an attempt to evaluate a complex air power problem. It is just a candle in a dark night. Further research should be undertaken to determine if a RSM method can be used to help improve the establishment of an airhead, to better understand a multitude of air-to-ground mission issues, or even to maximize something like Remote Piloted Vehicles (RPV) coverage. Different operational models (other than C2WSPTT) and math models (other than the linear model used herein) could be employed as comparison to historical or current operations would provide a venue for needed exploration. The case studied has several easily recognized limitations: What would have happened if the SAMs were left on? Are the unclassified generic scenarios realistic? The goal of the article was to explore if RSM would work on an air power problem, not to authenticate that the air power problem selected as the backdrop was valid. The article described using RSM in the 12 hours between ATO production and implementation. Including other parameters overlooked and more

complex non-linear math models and increasing the operational model speed and number of required runs might make RSM a costly tool to be used in Combat Operations during execution.

In a full factorial design, all possible factors and levels are studied simultaneously. Other techniques, such as Fractional Factorial or Central Composite Designs, can be used and may be more appropriate for the factors and levels studied. As the goal of this article was to explore if qualitative engineering could be used within an Air Power problem, a full factorial design method was selected. A secondary goal of using RSM in this article was to show the potentiality to save lives exposed to risk by the use of quantitative tools. In the real world, it most likely would require a small dedicated team trained in these techniques to study the problem and provide a quick overview to make decisions. The authors investigated whether a qualitatively created ATO can be optimized using RSM methods. Given an operational model that is a valid approximation to expected reality, response surface methods may be used to answer specific questions within the time available to promulgate those answers to fielded forces. Operation Air Power, as defined by the ATO produced by the AOC, may be quantitatively optimized, providing a more precise control method for fielded forces.

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Disclaimer

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APPENDIX A

Only units that lost aircraft in the referenced experiment are listed.

Fighter Squadron (FS)

Squadron (SQ)

Marine Fighter Attack Squadron (VMFA)

Navy Fighter Squadron (VF)

Experiment 1

Blue Unit	**Number Killed**	**Red Unit**	**Number Killed**
14 FS	4	21 FS	8
78 FS	4	22 FS	4
27 FS	4	23 FS	14
77 SQ	1	24 FS	4
94 FS	2	33 FS	6
95 FS	12	42 FS	2
VF 103	4	51 FS	6
VMFA 513	3	52 FS	6
		53 FS	6
Total	34	**Total**	56

Experiment 2

Blue Unit	Number Killed	Red Unit	Number Killed
14 FS	4	21 FS	8
78 FS	4	22 FS	4
27 FS	4	23 FS	14
522 FS	4	24 FS	4
77 SQ	2	33 FS	6
94 FS	2	42 FS	2
95 FS	12	51 FS	6
VF 103	4	52 FS	6
VMFA 513	3	53 FS	6
Total	39	**Total**	56

Experiment 3

Blue Unit	Number Killed	Red Unit	Number Killed
14 FS	2	21 FS	8
78 FS	4	22 FS	4
27 FS	4	23 FS	12
		24 FS	4
77 SQ	2	33 FS	6
94 FS	2	42 FS	2
95 FS	12	51 FS	6
VF 103	4	52 FS	6
VMFA 513	5	53 FS	6
Total	35	**Total**	54

Experiment 4

Blue Unit	Number Killed	Red Unit	Number Killed
14 FS	2	21 FS	8
78 FS	4	22 FS	4
27 FS	4	23 FS	12
		24 FS	4
77 SQ	2	33 FS	6
94 FS	2	42 FS	2
95 FS	12	51 FS	6
VF 103	4	52 FS	6
VMFA 513	5	53 FS	6
Total	35	**Total**	54

Experiment 5

Blue Unit	Number Killed	Red Unit	Number Killed
14 FS	4	21 FS	8
78 FS	4	22 FS	4
27 FS	4	23 FS	14
522 FS	4	24 FS	4
77 SQ	2	33 FS	6
94 FS	2	42 FS	2
95 FS	12	51 FS	6
VF 103	4	52 FS	6
VMFA 513	3	53 FS	6
Total	39	**Total**	56

Experiment 6

Blue Unit	**Number Killed**	**Red Unit**	**Number Killed**
14 FS	4	21 FS	8
78 FS	4	22 FS	4
27 FS	4	23 FS	14
		24 FS	4
77 SQ	1	33 FS	6
94 FS	2	42 FS	2
95 FS	12	51 FS	6
VF 103	4	52 FS	6
VMFA 513	3	53 FS	6
Total	34	**Total**	56

Experiment 7

Blue Unit	**Number Killed**	**Red Unit**	**Number Killed**
14 FS	4	21 FS	5
78 FS	4	22 FS	4
27 FS	4	23 FS	14
		24 FS	4
77 SQ	1	33 FS	6
94 FS	2	42 FS	2
95 FS	12	51 FS	6
VF 103	4	52FS	6
VMFA 513	3	53 FS	6
Total	34	**Total**	53

Experiment 8

Blue Unit	Number Killed	Red Unit	Number Killed
14 FS	2	21 FS	8
78 FS	4	22 FS	4
27 FS	4	23 FS	10
		24 FS	4
77 SQ	2	33 FS	6
		42 FS	2
95 FS	12	51 FS	6
VF 103	4	52 FS	6
VMFA 513	5	53 FS	6
Total	33	**Total**	52

Experiment 9

Blue Unit	Number Killed	Red Unit	Number Killed
14 FS	4	21 FS	8
78 FS	4	22 FS	4
27 FS	4	23 FS	14
		24 FS	4
77 SQ	1	33 FS	6
94 FS	2	42 FS	2
95 FS	12	51 FS	6
VF 103	4	52 FS	6
VMFA 513	3	53 FS	6
Total	34	**Total**	56

Experiment 10

Blue Unit	**Number Killed**	**Red Unit**	**Number Killed**
14 FS	6	21 FS	9
78 FS	4	22 FS	4
27 FS	4	23 FS	14
		24 FS	4
77 SQ	2	33 FS	6
94 FS	2	42 FS	2
95 FS	10	51 FS	6
VF 103	4	52 FS	6
VMFA 513	3	53 FS	6
Total	35	**Total**	57

Experiment 11

Blue Unit	**Number Killed**	**Red Unit**	**Number Killed**
14 FS	2	21 FS	9
78 FS	4	22 FS	4
27 FS	4	23 FS	12
75 FS	2	24 FS	4
77 SQ	2	33 FS	6
94 FS	2	42 FS	0
95 FS	10	51 FS	6
VF 103	4	52 FS	6
VMFA 513	5	53 FS	6
Total	35	**Total**	53

Experiment 12

Blue Unit	Number Killed	Red Unit	Number Killed
14 FS	2	21 FS	9
78 FS	4	22 FS	4
27 FS	4	23 FS	12
		24 FS	4
77 SQ	2	33 FS	6
94 FS	2		
95 FS	10	51 FS	6
VF 103	4	52 FS	6
VMFA 513	5	53 FS	6
Total	33	**Total**	53

Experiment 13

Blue Unit	Number Killed	Red Unit	Number Killed
14 FS	2	21 FS	9
78 FS	4	22 FS	4
27 FS	4	23 FS	14
		24 FS	4
77 SQ	2	33 FS	6
94 FS	2		
95 FS	10	51 FS	6
VF 103	4	52 FS	6
VMFA 513	3	53 FS	6
Total	31	**Total**	55

Experiment 14

Blue Unit	Number Killed	Red Unit	Number Killed
14 FS	4	21 FS	9
78 FS	4	22 FS	4
27 FS	4	23 FS	14
		24 FS	4
77 SQ	2	33 FS	6
94 FS	2		
95 FS	10	51 FS	6
VF 103	4	52 FS	6
VMFA 513	3	53 FS	6
Total	33	**Total**	55

Experiment 15

Blue Unit	Number Killed	Red Unit	Number Killed
14 FS	2	21 FS	9
78 FS	4	22 FS	4
27 FS	4	23 FS	12
		24 FS	4
77 SQ	4	33 FS	6
94 FS	2		
95 FS	10	51 FS	6
VF 103	4	52 FS	6
VMFA 513	5	53 FS	6
Total	35	**Total**	53

Experiment 16

Blue Unit	Number Killed	Red Unit	Number Killed
14 FS	4	21 FS	9
78 FS	4	22 FS	4
27 FS	4	23 FS	12
75 FS	2	24 FS	4
77 SQ	4	33 FS	6
94 FS	2	42 FS	2
95 FS	10	51 FS	6
VF 103	4	52 FS	6
VMFA 513	5	53 FS	6
Total	39	**Total**	55